SEARCHING FOR THE HIGGS BOSON

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- Collider searches for the Higgs
- Is it the SM Higgs boson?
- SUSY & other BSM Higgs sectors

Some recommended references

The Anatomy of electro-weak symmetry breaking. I/II: [SM & MSSM]
Abdelhak Djouadi, hep-ph/0503172 and 0503173.

Les Houches Physics at TeV Colliders 2005, SM/Higgs WG summary report.
C. Buttar et al., hep-ph/0604120.

Physics interplay of the LHC and the ILC,
LHC/LC Study Group (G. Weiglein et al.), hep-ph/0410364.

Higgs Physics at the Linear Collider,
John Gunion, H. Haber & R. Kooten, hep-ph/0301023.

Tesla TDR, Part III, hep-ph/0106315.

IS IT THE HIGGS OR NOT?

Or, “after the champagne”

Confirm that candidate resonance is SM Higgs

$\longrightarrow$ SM has very specific predictions for its quantum numbers

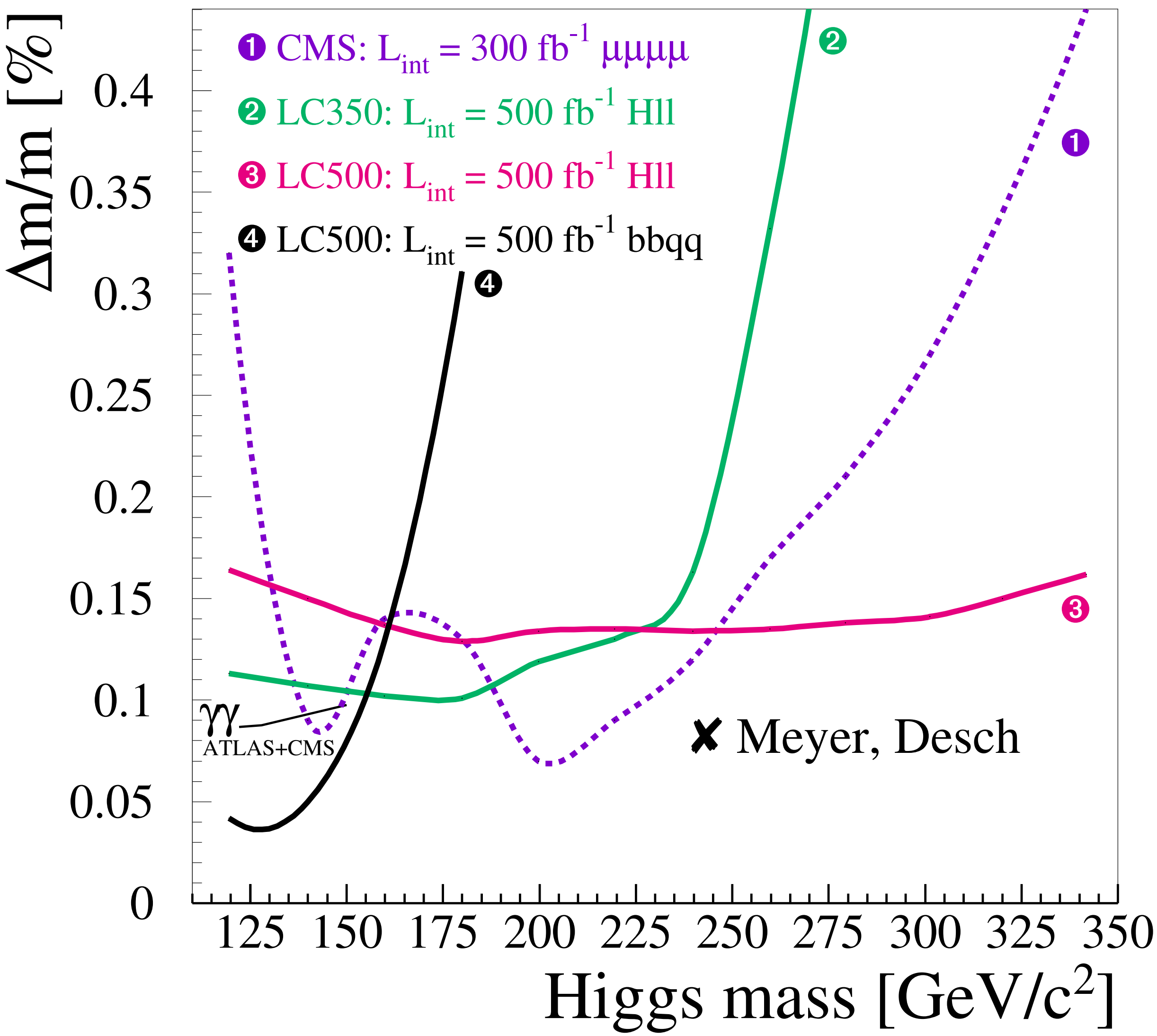
- colorless – trivial
- neutral – trivial
- mass – measure as accurately as possible
- spin 0
  - · easy to confirm as boson by decay products
  - · if $H \rightarrow \gamma\gamma$ seen, not $S = 1$
  - · $S \geq 2$ is exotic – ignore for now
- CP even
- gauge couplings: g_W w/ tensor structure $g^{\mu\nu}$
- Yukawa couplings: $|Y_f| = \frac{m_f}{\mathrm{v}}$
  - · note: must use running couplings ($m_f(M_H)$)
- spontaneous symmetry breaking potential

▶ these things get increasingly difficult

$\longrightarrow$ many look like SM, but we want precision to distinguish BSM

Mass measurement at LHC & ILC

Free parameter in the SM, but not necessarily BSM.



LHC and ILC have comparable ability: ILC is $\sim$ twice as good if M_H low.

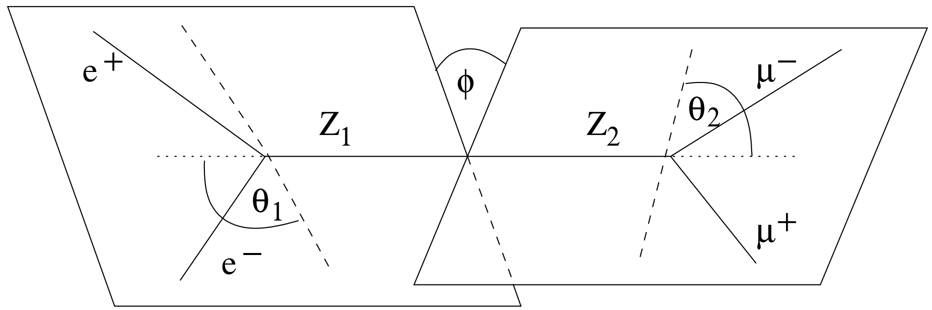
Spin & CP measurements at LHC

1. Nelson technique, $H \to ZZ \to 4\ell$: relative Z decay planes

$F(\phi) = 1 + \alpha\cos(\phi) + \beta\cos(2\phi)$

SM: $\alpha = \alpha(M_H) > \frac{1}{4}$, $\beta = \beta(M_H)$

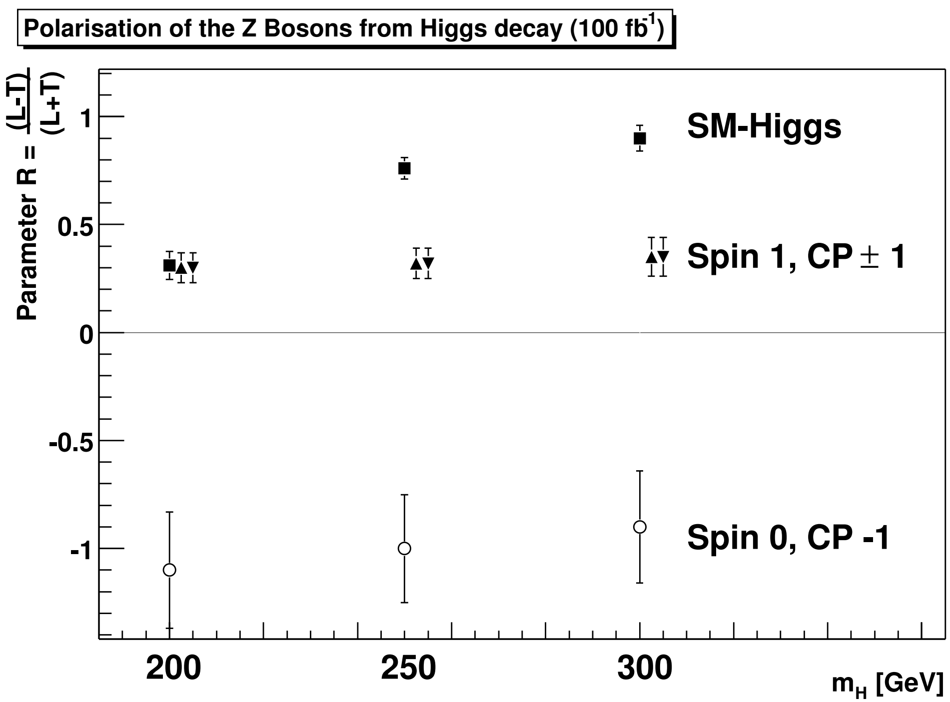
pseudoscalar: $\beta = -0.25$



studied w/ detector simulation for $M_H > 200$ GeV:

great, but need to be studied for $M_H < 200$ GeV

Note: $S = 1$ not possible for gg collisions



Spin & CP measurements at LHC

2. CMMZ technique, $H \to ZZ^{(*)} \to 4\ell$: extension to Nelson technique

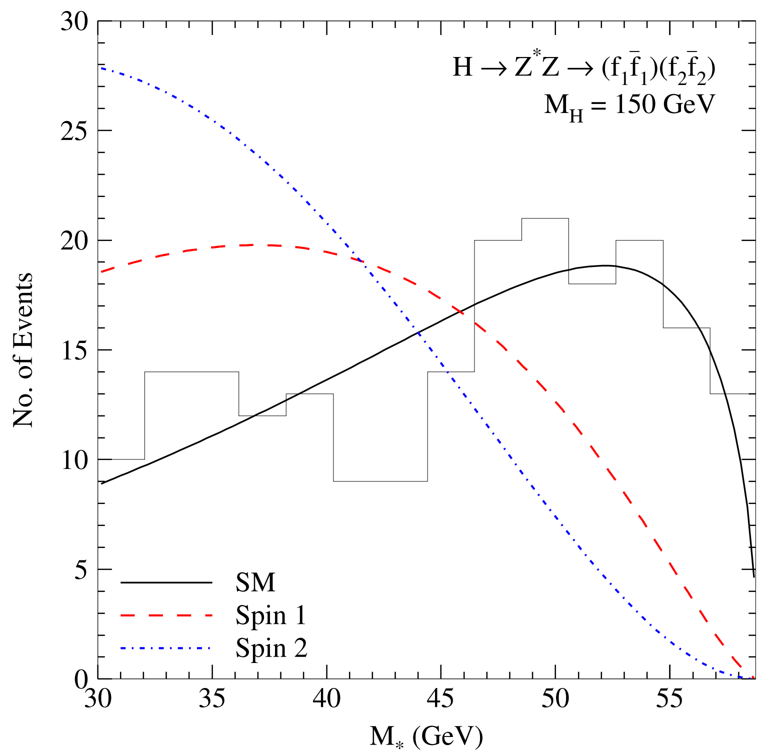
Above ZZ threshold: Nelson technique must be extended;

$J^P = 2^+, 4^+, \ldots$ can mimic 0^+ Higgs in decays to ZZ

$\longrightarrow$ rule out high-spin states via lack of angular correlations between initial state and Higgs flight direction

Below ZZ threshold: look at M_* (off-shellness of Z) dist'bn

$\frac{d\Gamma}{dM_*}$ is a function of spin:



Spin & CP measurements at LHC

3. WBF tagging jets, $H \longrightarrow$ anything

▶ reflects tensor & CP structure of HVV vertex

· two $SU(2)_L \times U(1)_Y$ gauge-invariant D6 operators to consider:

$$\mathcal{L}_6 \;=\; \frac{g^2}{2\Lambda_{e,6}}(\Phi^\dagger\Phi)W^+_{\mu\nu}W^{-\mu\nu} \;+\; \frac{g^2}{2\Lambda_{o,6}}(\Phi^\dagger\Phi)\widetilde{W}^+_{\mu\nu}W^{-\mu\nu}$$

expand Φ field to get effective D5 operators:

$$\mathcal{L}_5 \;=\; \frac{1}{\Lambda_{e,5}}HW^+_{\mu\nu}W^{-\mu\nu} \;+\; \frac{1}{\Lambda_{o,5}}H\widetilde{W}^+_{\mu\nu}W^{-\mu\nu}$$

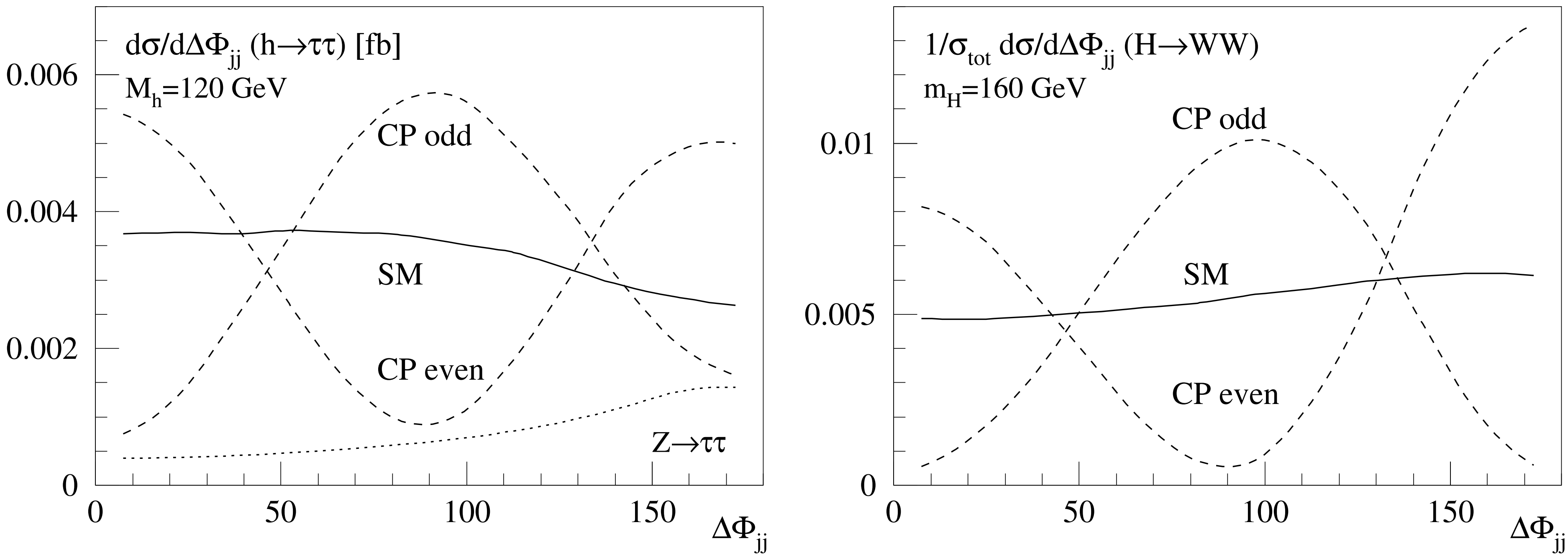
D5 CP-even operator is distinctive:

$$\mathcal{M}_{e,5} \propto \frac{1}{\Lambda_{e,5}}J_1^\mu J_2^\nu\left[g_{\mu\nu}(q_1\cdot q_2) - q_{1,\nu}q_{2,\mu}\right] \sim \frac{1}{\Lambda_{e,5}}\left[J_1^0 J_2^0 - J_1^3 J_2^3\right]\vec{p}_T^{\,j1}\cdot\vec{p}_T^{\,j2}$$

D5 CP-odd operator also distinctive:

$\epsilon_{\mu\nu\rho\delta}$ is nonzero only if 4 external p_i independent (not coplanar)

Azimuthal tagging jet distributions



WBF H analyses don't use ϕ_j info., so operator structure easily revealed

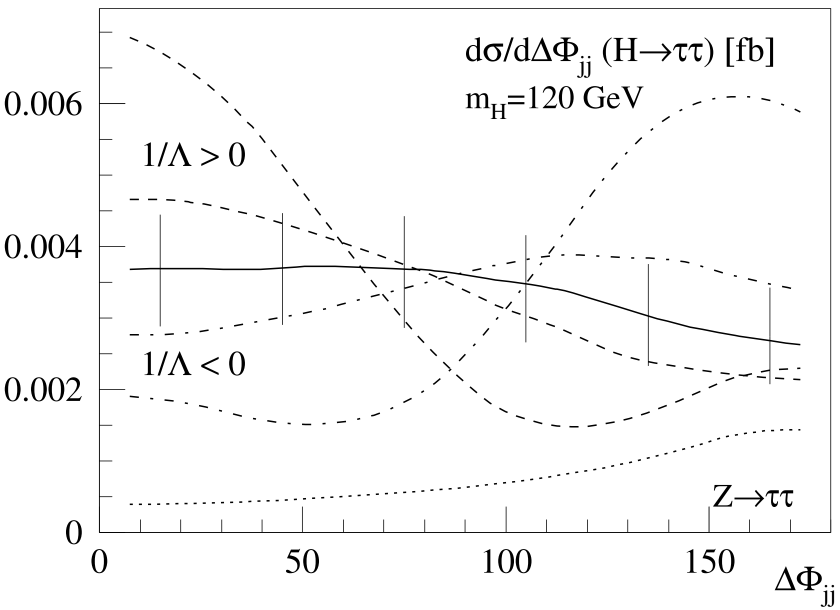
- guarantee: ≥ 1 of WBF $H \to \tau^+\tau^-, W^+W^-$ work for all M_H

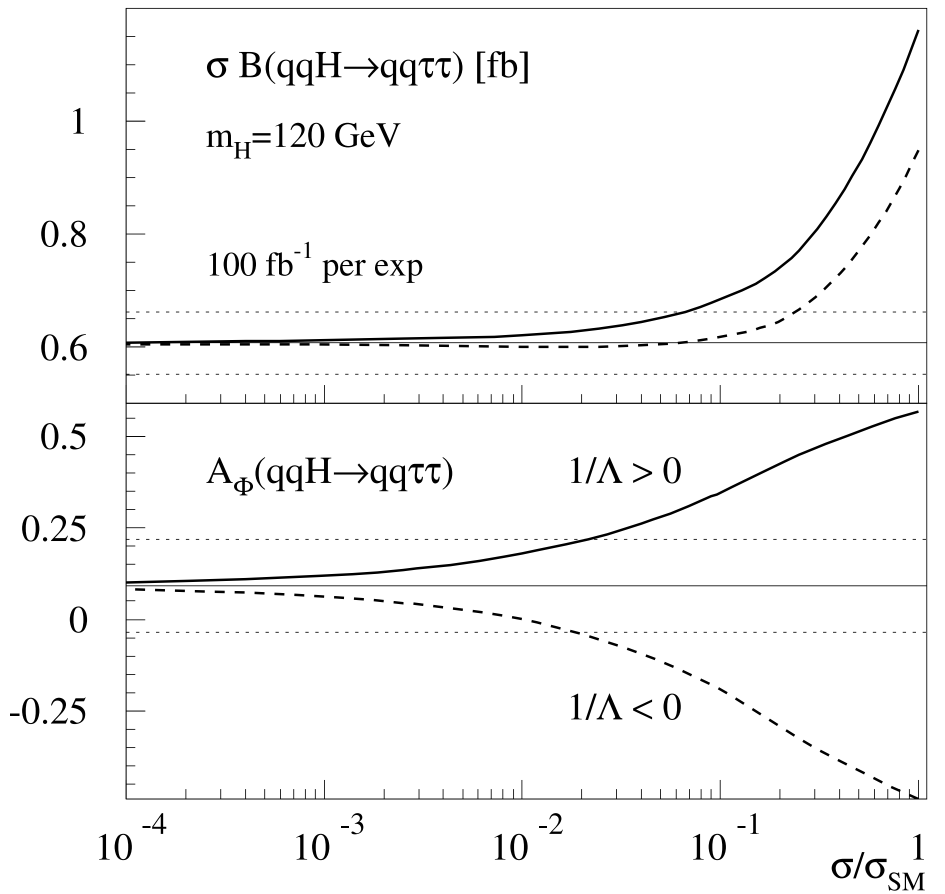
$\longrightarrow$ trivial to distinguish pure cases, but what about SM + D5 interf.?

SM-D5 Interference

SM $g^{\mu\nu}$ and D5 CP-even couplings interfere, distorting ϕ_{jj} distribution
Obvious choice: asymmetry observable:

$$A_\phi = \frac{\sigma(\Delta\phi_{jj} < \pi/2) - \sigma(\Delta\phi_{jj} > \pi/2)}{\sigma(\Delta\phi_{jj} < \pi/2) + \sigma(\Delta\phi_{jj} > \pi/2)}$$





Λ_5[TeV]	16	5.0	1.6	0.5
Λ_6[TeV]	1.8	0.7	0.4	0.23

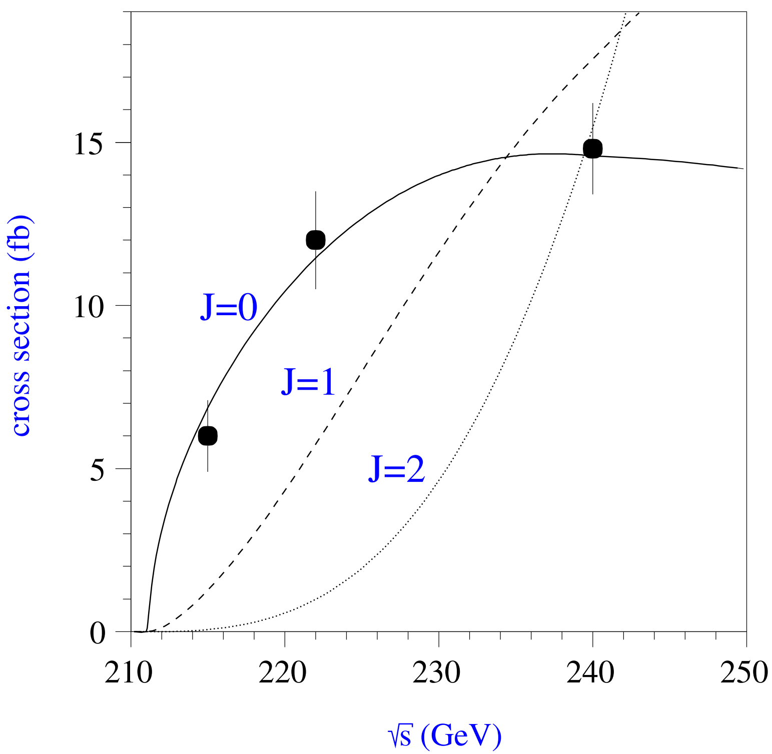
$\longrightarrow$ meas'mt sensitive to $\Lambda_6 \sim 1$ TeV

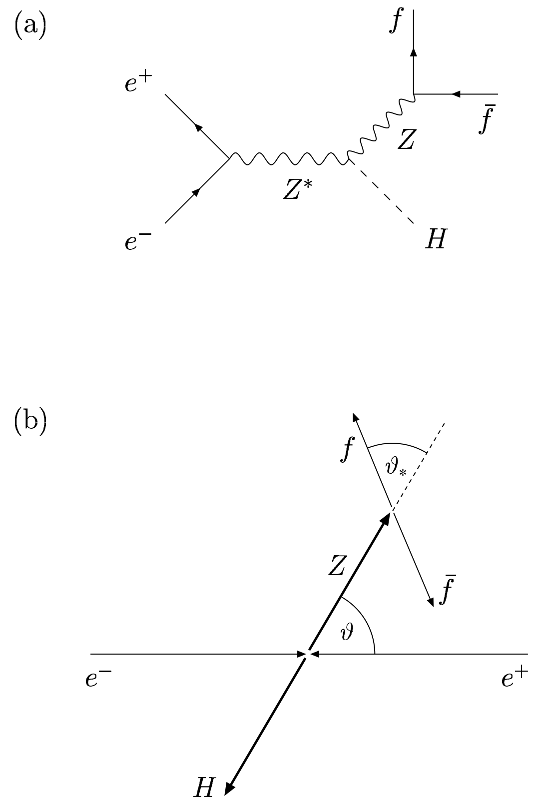
Note:

ignores $gg \rightarrow Hgg$ contamination!

Spin & CP measurements at ILC

- J and P totally determined by σ_{ZH} threshold rise & angular dist'bn





$$\frac{d\sigma}{d\cos\theta_Z} \propto \beta\left[1 + a\beta^2\sin^2\theta_Z + b\eta\beta\cos\theta_Z + \eta^2\beta^2(1+\cos^2\theta_Z)\right]$$

where η is a pseudoscalar coupling to Z

· can perform a more sophisticated analysis for admixtures

Higgs couplings measurements at LHC

We need to determine g_{HVV} as well as all Y_f. Is this possible?

The LHC measures *rates*:

$\sigma\cdot$ BR extracted by removing collider & phase space effects w/ Monte Carlo

Problem with number of observables:

- given n couplings, suppose n final states observed
- at LHC, for light M_H, $\left(\sigma_H \cdot \mathrm{BR}\right)_i \propto \left(\Gamma_p \frac{\Gamma_d}{\Gamma_H}\right)_i$
- n counts all Γ_p,Γ_d, but we're one measurement short to obtain Γ_H, total width

Old idea: measure ratios of BR's (cf. e.g. ATLAS TDR)

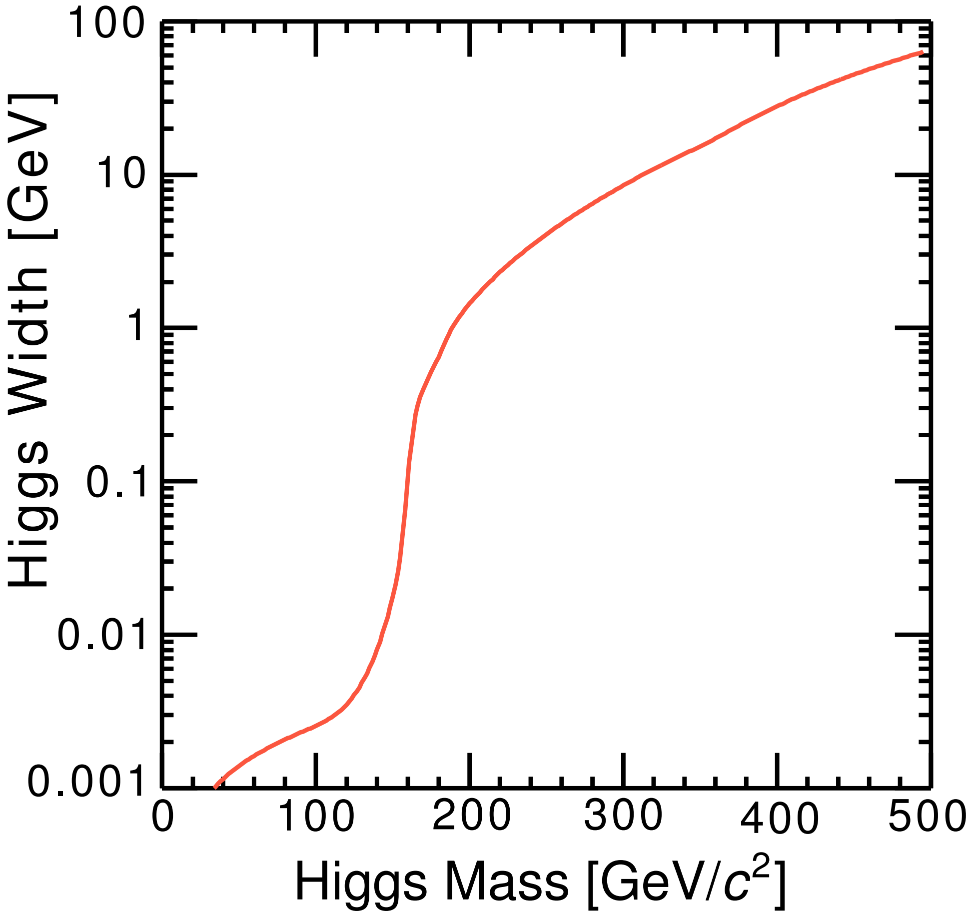
$\longrightarrow$ can discern SM from some BSM, but not well

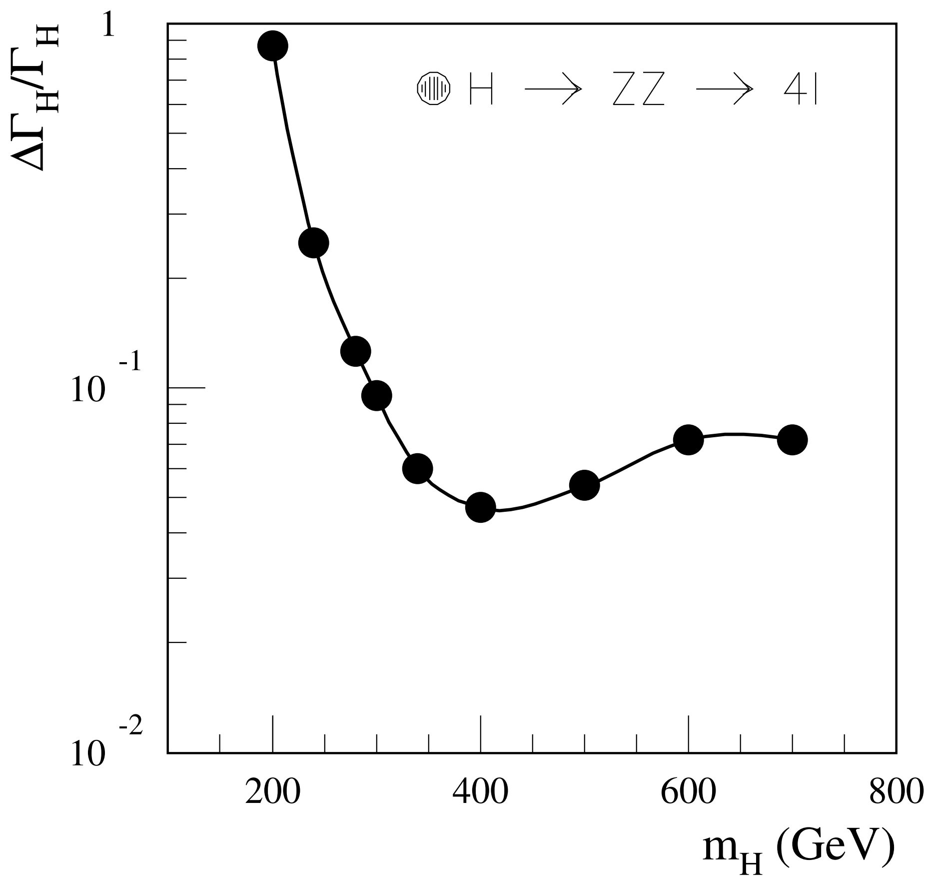
$\longrightarrow$ does not measure absolute couplings

New idea: sum of partial widths is total width, w/ mild theory assumptions

Note: also need to parameterize possible couplings to non-SM particles

So what is the actual Higgs width?





Somewhere around 250-300 GeV the detector can resolve the width.

Below that, we resort to other techniques.

Let's parameterize $\left(\sigma \cdot \mathrm{BR}\right)_{i,\mathrm{exp}}$ via the products $\left(\frac{\Gamma_p \Gamma_d}{\Gamma_H}\right)_i$.

At LHC, we have $X_\gamma, X_\tau, X_W, X_Z, Y_\gamma, Y_W, Y_Z, Z_b, Z_\gamma, Z_W$

where X_i = WBF, Y_i = GF, and Z_i = $t\bar{t}H$ production $\left(\text{really} \propto \frac{Y_t^2 \Gamma_d}{\Gamma_H}\right)$

Note: any X_i,Y_i,Z_i=0 is <u>still</u> a measurement!

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- In the SM, total width is sum of partial widths:

$$\Gamma_H = \Gamma_W + \Gamma_Z + \Gamma_b + \Gamma_g + \Gamma_\tau + \Gamma_\gamma \quad \left(\Gamma_t = 0 \text{ for } M_H < 2m_t\right)$$

Recall: $t\bar{t}H, H \to b\bar{b}$ not so good, so assume $\frac{\Gamma_b}{\Gamma_\tau} = 3c_{\mathrm{QCD}} \frac{m_b^2}{m_\tau^2}$,
c_{QCD} contains P.S. + NNLO corrections.

Can also assume Γ_W related to Γ_Z by $SU(2)_L$, but not necessary.

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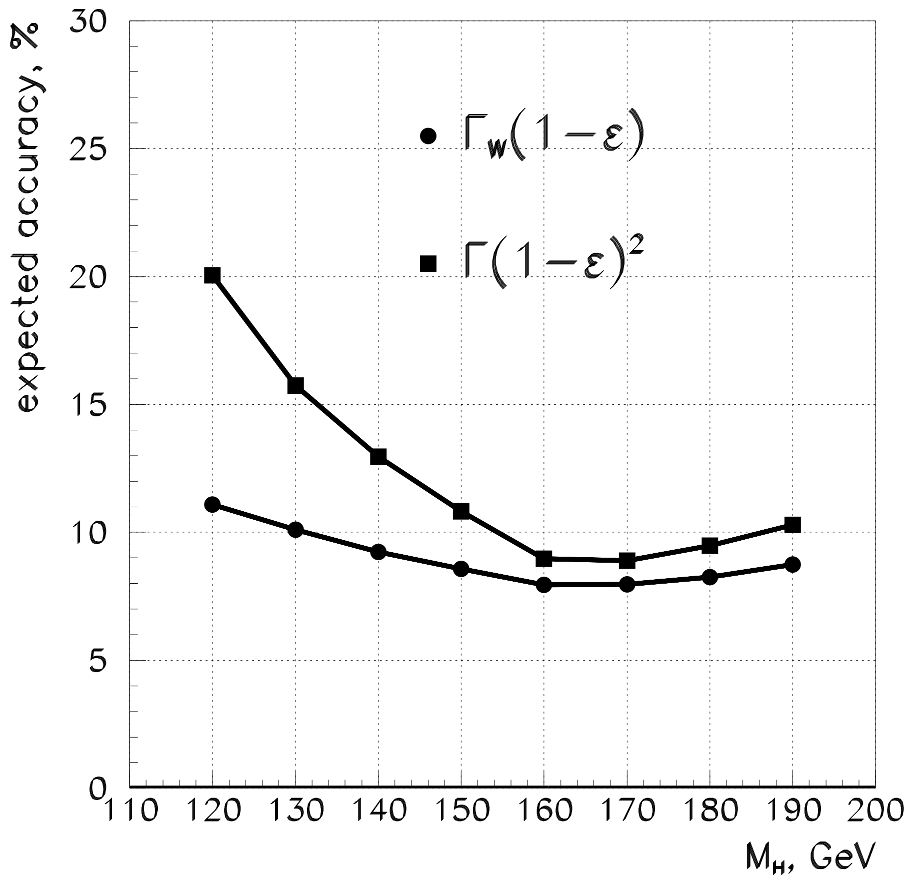
- Now consider $\widetilde{\Gamma}_W = X_\tau(1 + r_b) + X_W(1 + r_Z) + X_\gamma + \widetilde{X}_g$

  where $\widetilde{X}_g$ from Y_γ and other data:

$$\widetilde{\Gamma}_W = \left(\Gamma_\tau + \Gamma_b + \Gamma_W + \Gamma_Z + \Gamma_\gamma + \Gamma_g\right) \frac{\Gamma_W}{\Gamma_H} = (1 - \epsilon)\Gamma_W$$

We now have a good lower bound on Γ_W from data.

The total width is then $\Gamma_H = \frac{\widetilde{\Gamma}_W^2}{X_W}$ and error goes as $(1-\epsilon)^{-2}$.



(assumes 5% uncer. on X_i, 20% on Y_i, no Z_i)

$\longrightarrow$ pretty good, but this has flaws & tastes unsatisfactory (r_b, etc.)

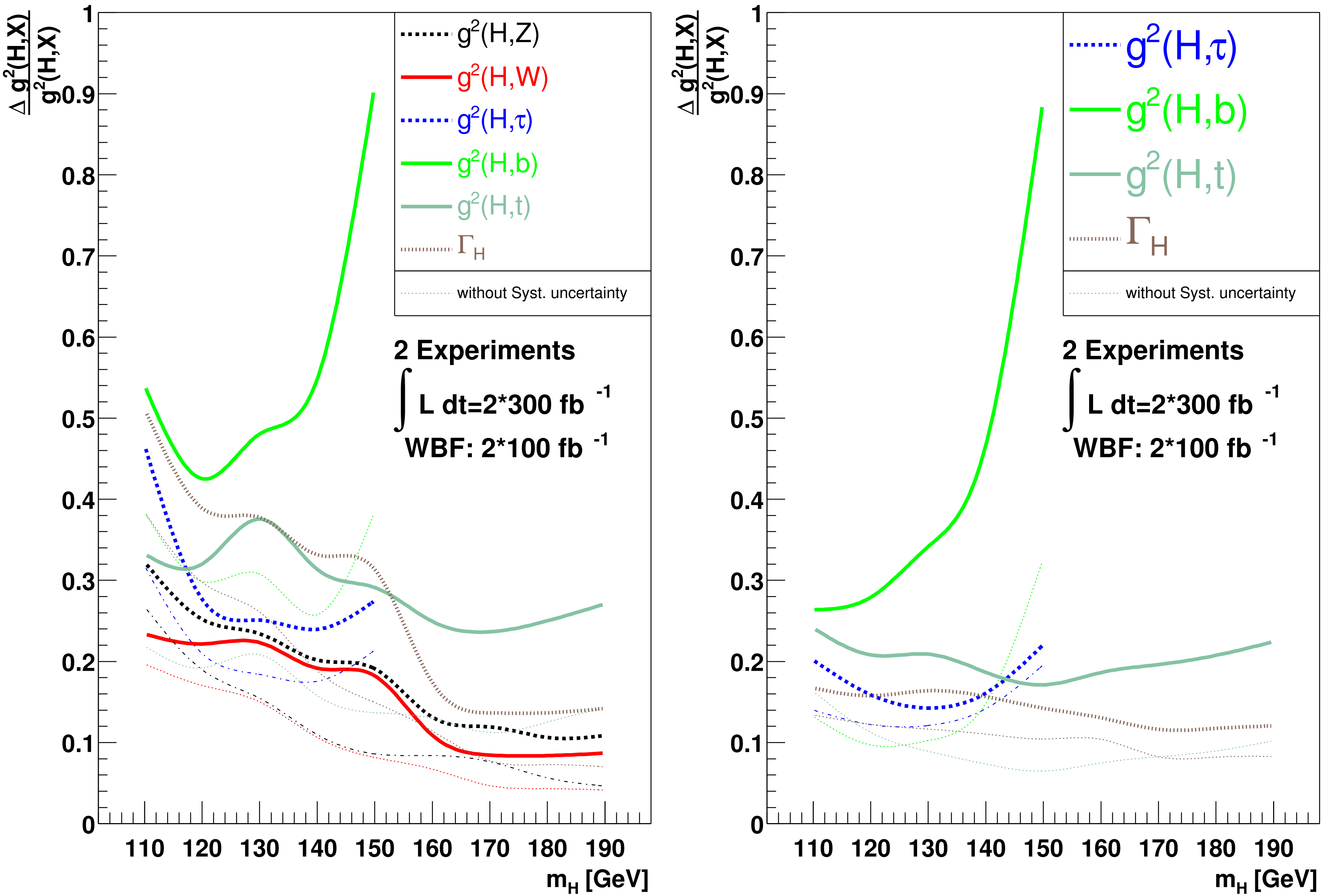
More sophisticated: do a global least-likelihood fit to data, using:

$$\sigma_H \cdot \mathrm{BR}(H \to xx) \;=\; \frac{\sigma_H^{\mathrm{SM}}}{\Gamma_p^{\mathrm{SM}}} \cdot \boxed{\frac{\Gamma_p \Gamma_d}{\Gamma_H}}$$

- as before, "sum" of channels provides $\Gamma_H(\mathrm{min})$, but found via fit
- only assumption: $\Gamma_V \leq \Gamma_V^{\mathrm{SM}}$; valid in *any* doublet(+singlet) model
  $\longrightarrow \frac{\Gamma_V^2}{\Gamma_H}$ then provides $\Gamma_H(\mathrm{max})$
- assign exp. stat. & syst. uncer.'s, based on det. sim. studies plus theory
- allow for unobsv. decays via Γ_{extra}; allow additional loop contributions
- fix M_H

Channels used in current analysis:

- $gg \to H \to W^+W^-, ZZ, \gamma\gamma$
- WBF $H \to W^+W^-, ZZ, \gamma\gamma, \tau^+\tau^-$
- $t\bar{t}H, H \to W^+W^-, \gamma\gamma, b\bar{b}$
- $WH, H \to W^+W^-, \gamma\gamma$
- $ZH, H \to \gamma\gamma$



Left: no additional assumptions.

Right: assume nothing new in loops, $g_W = g_W^{\mathrm{SM}}$.

Bottom line: LHC *can* measure absolute Higgs couplings.

Notes on Higgs couplings results:

1. assumes WBF not possible at high-lumi (not true, but degraded)
2. assumes very bad systematic errors
3. assumes lack of improved QCD understanding for S & B
4. does not yet include $H \longrightarrow$ invis. analyses (WBF,ZH)
5. WBF analyses don't yet use minijet veto

Improvements coming soon:

- better systematics on $H \longrightarrow \tau^+\tau^-$ from new fitting tricks
- $H \longrightarrow$ invis. analyses
- QCD NNLO systematic uncer. reduction for $gg \longrightarrow H$ channels
- fitting for M_H

► Realize: if new physics found, recalc. Higgs rates (loops, etc.) including it.

What is this about overestimating the QCD error in $gg \to H$?

Recall our couplings extraction formula:

$$\sigma_H \cdot \mathrm{BR}(H \to xx) \;=\; \frac{\sigma_H^{\mathrm{SM}}}{\Gamma_p^{\mathrm{SM}}} \cdot \boxed{\frac{\Gamma_p \Gamma_d}{\Gamma_H}}$$

Global fit analysis assumes $\triangle\left(\frac{\sigma}{\Gamma}\right)_{gg\to H} = 20\%$: this is a huge limitation.

But *really* $15\text{-}20\%$ uncertainty is for just $\sigma_{gg\to H}$.
The QCD NNLO corrections go as:

$$\Gamma \sim \alpha_s^2(\mu_R) C_1^2(\mu_R) [1 + \alpha_s(\mu_R) X_1 + ...]$$

$$\sigma \sim \alpha_s^2(\mu_R) C_1^2(\mu_R) [1 + \alpha_s(\mu_R) Y_1 + ...]$$

Most of the scale variation uncertainty drop out in the ratio:
$\triangle\left(\frac{\sigma}{\Gamma}\right)_{gg\to H} = \pm 5\%$ is much more accurate.

Higgs couplings measurements at ILC

At an e^+e^- collider we can measure the total ZH rate *exactly*.

Look for $Z \to \ell^+\ell^-$ at the pole and calculate the recoil/missing mass; from conservation of momentum, we find:

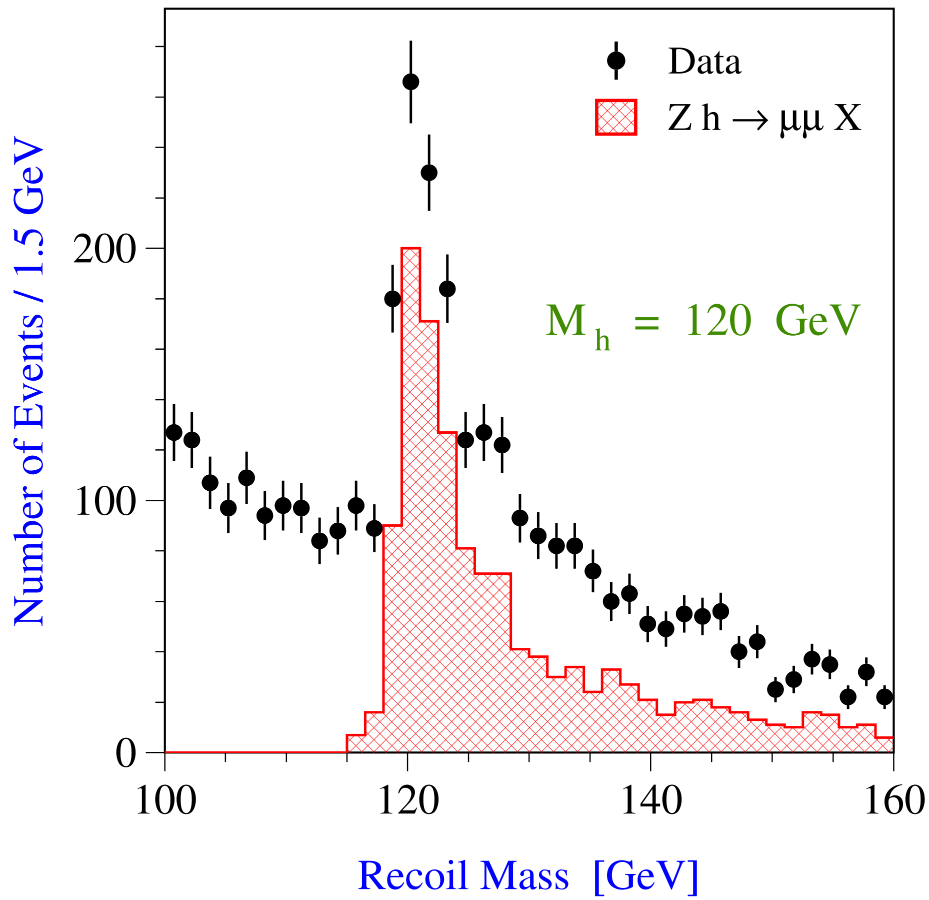
$$M_H^2 = p_H^2 = (p_+ + p_- - p_Z)^2 = s + M_Z^2 - 2\sqrt{s}E_Z$$

Canonical example:

Achieves $\triangle\sigma_{ZH} \approx 2.5\%$

for a light Higgs.

$\longrightarrow$ now we know g_{HZZ} to $\sim 1\%$



Higgs couplings @ ILC

Now to the other couplings: can get from various BR's.

But we need the total width for that – how to get? $\Gamma_H = \frac{\Gamma(H \to X)}{\mathrm{BR}(X)}$

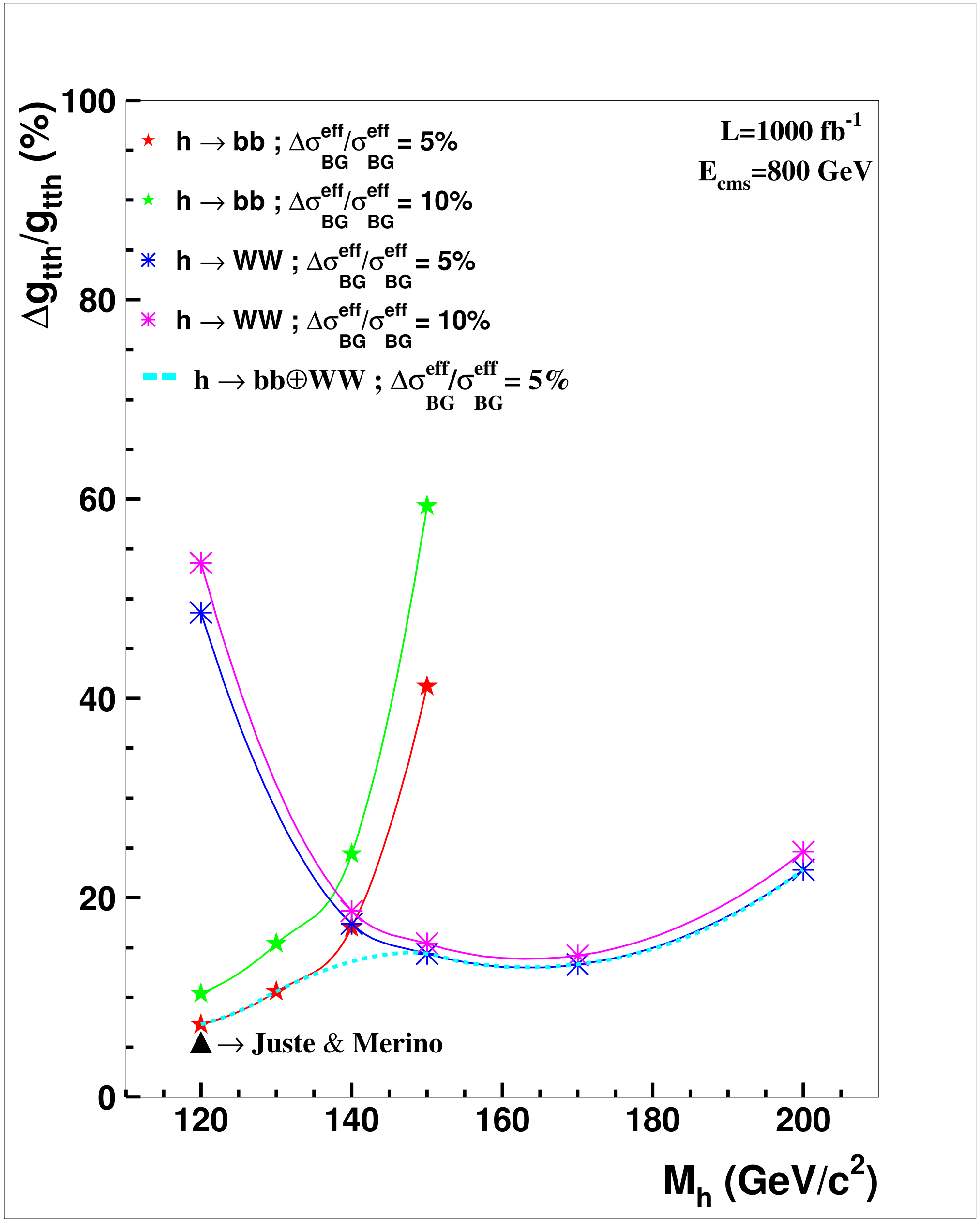
Step-by-step:

1. measure σ_{ZH} (super-precise)
2. measure best BR's in ZH; e.g. $H \to b\bar{b}, \gamma\gamma, W^+W^-$
3. look in WBF H production with same final state ($H \to b\bar{b}, \gamma\gamma, W^+W^-$)
   this gives us $\Gamma(H \to W^+W^-)$
4. $\Gamma_H = \frac{\Gamma(H \to W^+W^-)}{\mathrm{BR}(H \to W^+W^-)}$
5. other BR's now give individual partial widths ($\therefore$ couplings)

M_H (GeV)	120	140	160	180	200	220
Decay	Relative partial width precision (%)					
$b\bar{b}$	1.9	2.6	6.5	12.0	17.0	28.0
$c\bar{c}$	8.1	19.0				
$\tau^+\tau^-$	5.0	8.0				
gg	4.8	14.0				
W^+W^-	3.6	2.5	2.1			
ZZ			16.9			
$\gamma\gamma$	23.0					
$Z\gamma$		27.0				

Higgs couplings @ ILC

Most recent ILC (800 GeV) analysis for $e^+e^- \to t\bar{t}H$



► competetive w/ LHC for $M_H > 140$ GeV,
cover LHC hole for $M_H < 140$ GeV

The SM Higgs potential

$$V(\Phi) = \mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$

$\mu^2 \to < 0$ breaks sym. spontaneously, min. at $v = \sqrt{\frac{-\mu^2}{\lambda}}$

λ fixed by $VV \to HH, HHH$ unitarity: $\quad \lambda_{SM} = M_H^2 / 2v^2$

$\longrightarrow$ gives 3,4-point self-couplings $\quad \lambda_{3H,4H} = -6v\lambda, -6\lambda$

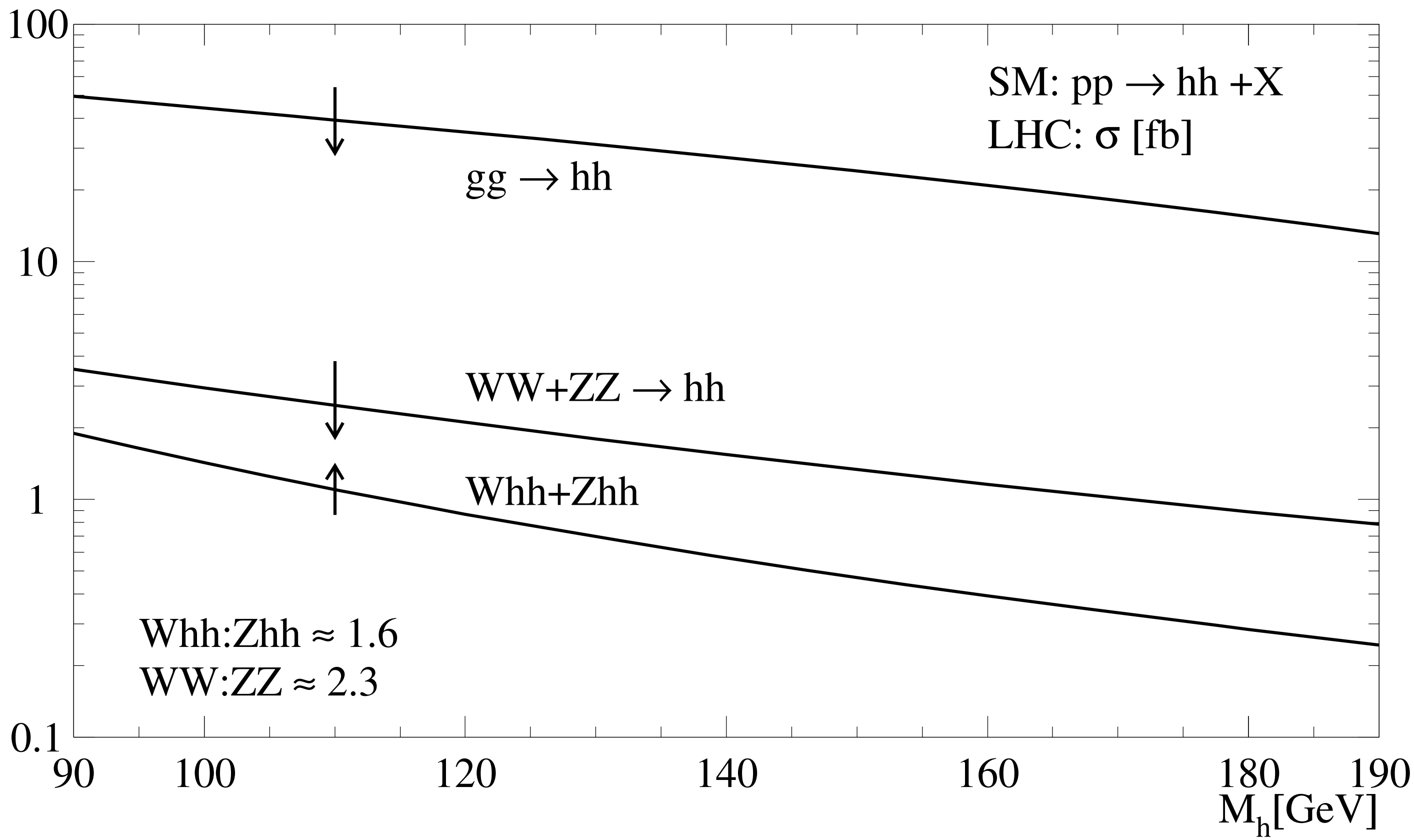
Phenomenological approach: measure coefficients of effective potential

$$\boxed{V(\eta_H) = \frac{1}{2} M_H^2 \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \tilde{\lambda} \eta_H^4}$$

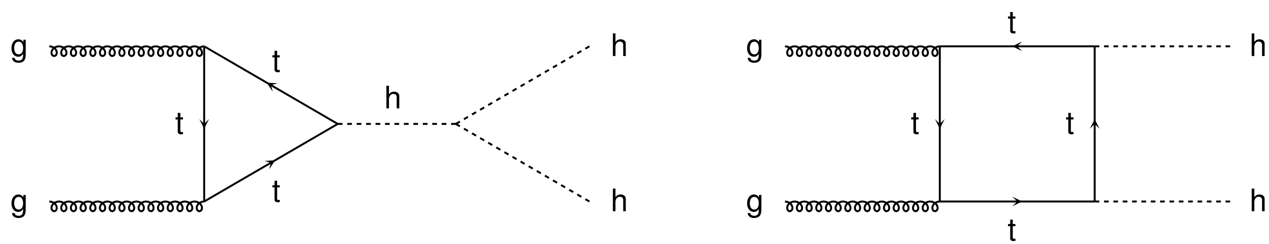
$\longrightarrow \quad \lambda$, $\tilde{\lambda}$ now free parameters

- *need direct observation of HH, HHH to measure*

Step 1: HH production at LHC



SM diagrams for largest contribution:



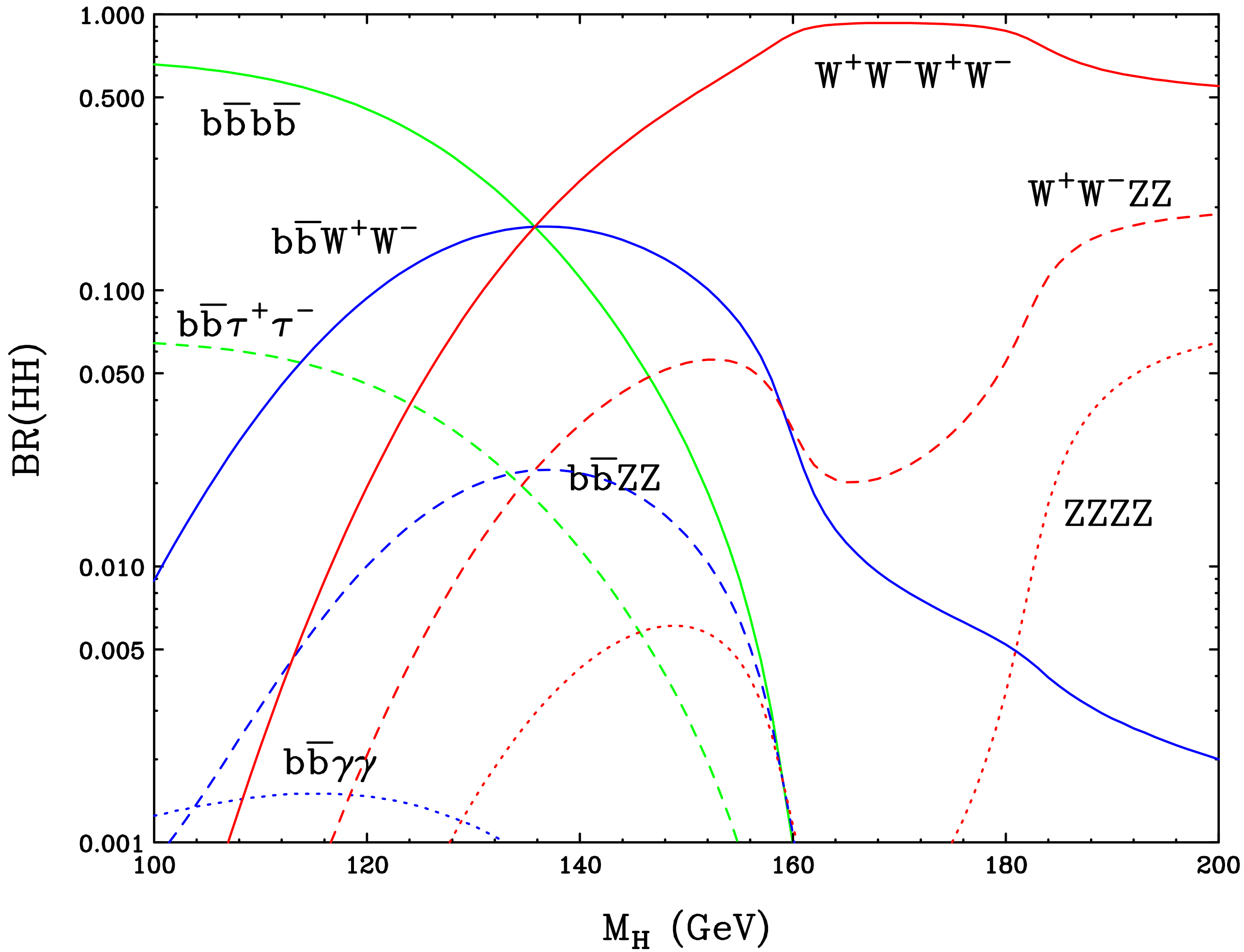
$\longrightarrow$ *interfere destructively!*

$gg \longrightarrow HH$ @ LHC: $\mathcal{O}$(10k) events in 300 fb^{-1} (“Run I”)

Channels to measure σ_{hh}

Consider final state to observe hh events:

Higgs decays to SM pairs: kinematically- allowed $f\bar{f}$, or off-shell WW/ZZ



small M_h: $4b,\ b\bar{b}\tau^+\tau^-,\ b\bar{b}\ell^+\ell^-\not{p}_T, b\bar{b}\gamma\gamma$

large M_h: $4W \longrightarrow$ multileptons

For M_h large, examine $4W$ final states:

$HH \to W^+W^-W^+W^-$ has myriad decays;

choose multilepton final states for trigger and QCD background rejection:

$\ell^\pm \ell^\pm + 4j \quad , \qquad \ell^\pm \ell^\pm \ell^\mp + 2j$

Note: no mass reconstruction!

principal backgrounds are

$$WWWjj,\ t\bar{t}W,\ t\bar{t}j,\ t\bar{t}Z/\gamma^*,\ WZ + 4j$$

must also consider

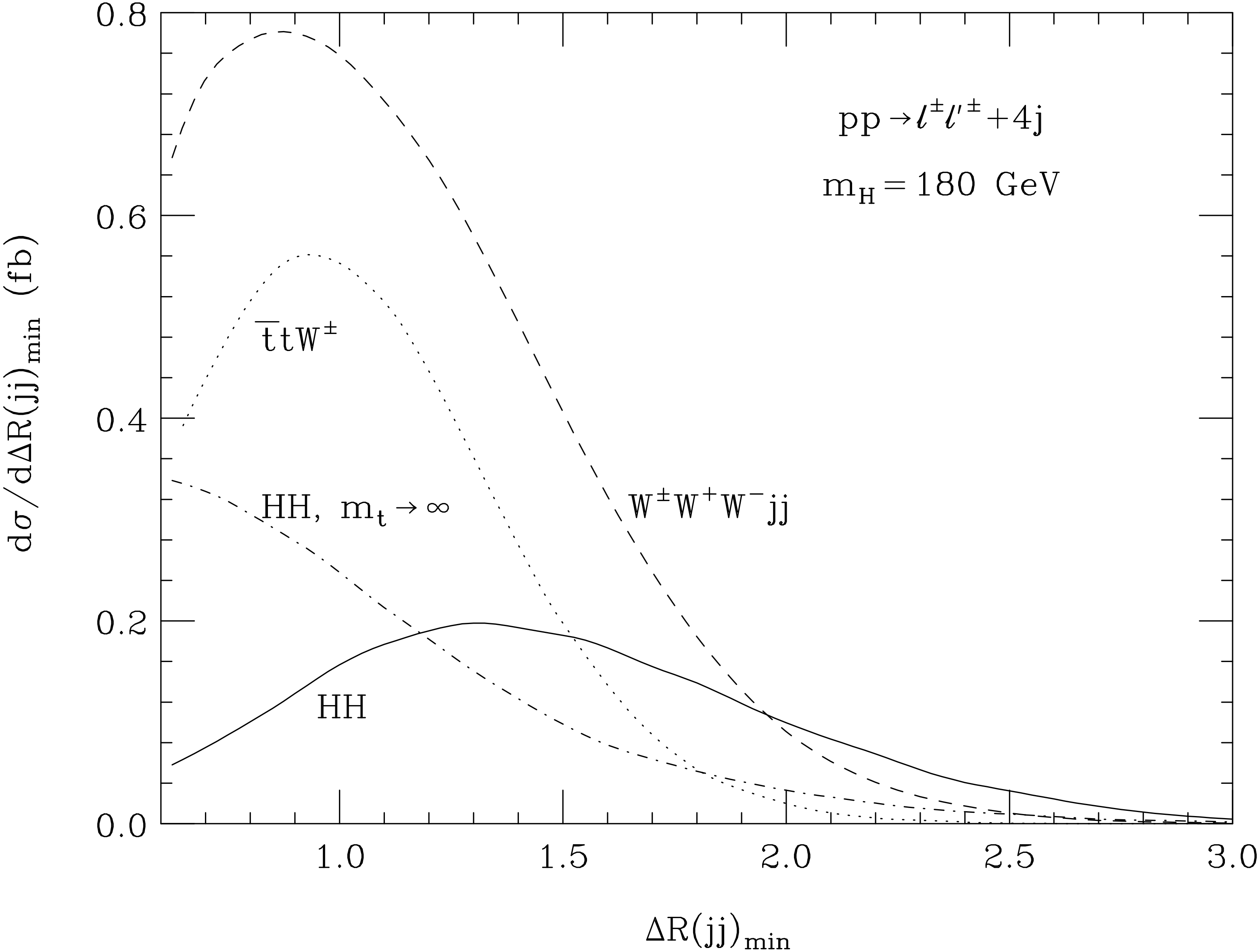
$t\bar{t}t\bar{t},\ 4W,\ WW + 4j,\ WWZjj$ as well as DPS & overlap

Notes:

1. Must use exact (finite-m_t) matrix elements for signal!
   $\longrightarrow K$-factor known only in $m_t \to \infty$ limit; multiply
2. $\sigma_{DPS} = \frac{\sigma_1 \sigma_2}{\sigma_{eff}}$ w/ $\sigma_{eff} \sim 15$ mb & P.S. restriction (x_i)
3. $\sigma_{ov} = \frac{1}{2}\sigma_1\sigma_2\mathcal{L}_{bc}, \quad \mathcal{L}_{bc} = \mathcal{L}\Delta\tau$ fn. of lumi
4. BR(W^+W^-) and Y_t must be known very precisely (systematic uncertainty)

A warning about using effective Lagrangians:

normalization ok, but gives wrong kinematics!

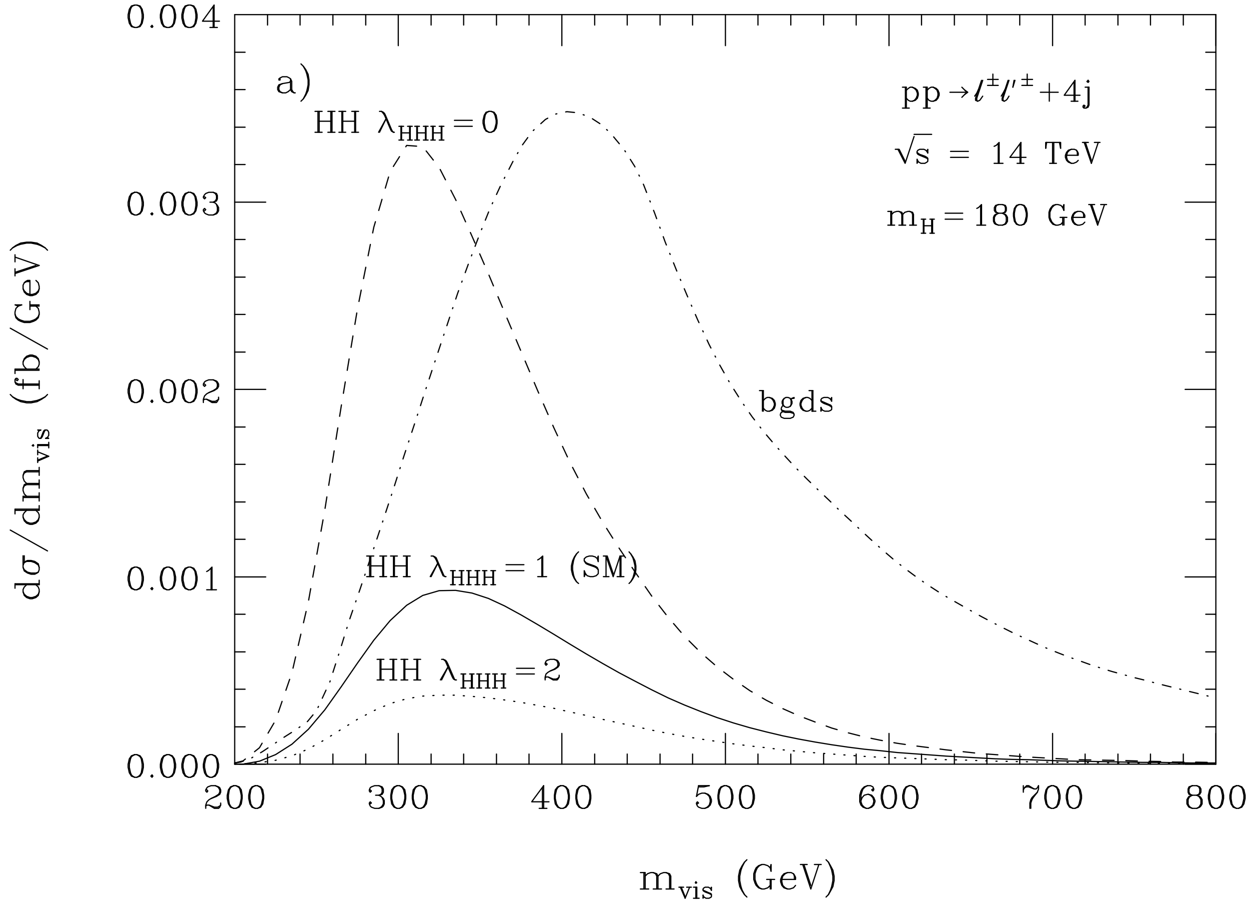


$HH \to 4W$ signal characteristics

Can't reconstruct the event completely (two missing neutrinos);

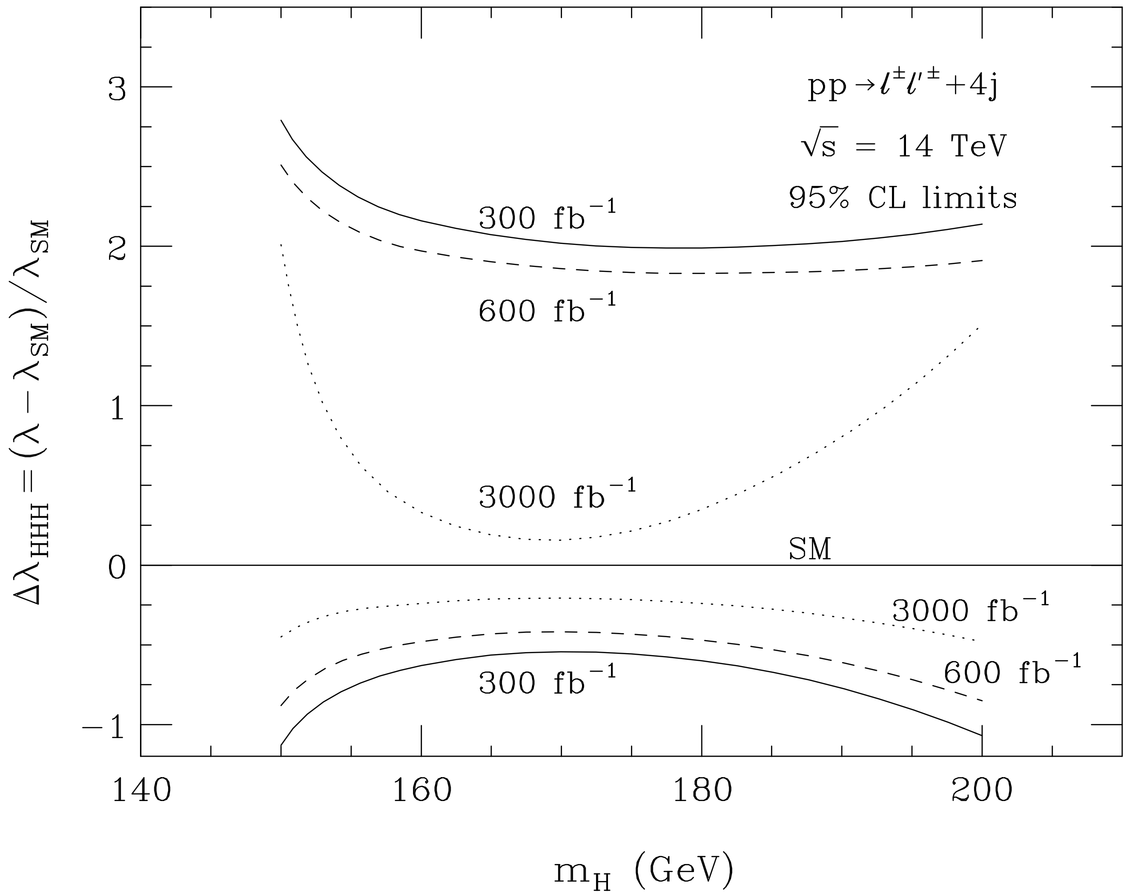
simply take the visible invariant mass, $m_{vis}^2 = [\sum_i E_i]^2 - [\sum_i \mathbf{p}_i]^2$

HH is 2-body: m_{vis} peak near threshold; multi-body bkgs won't



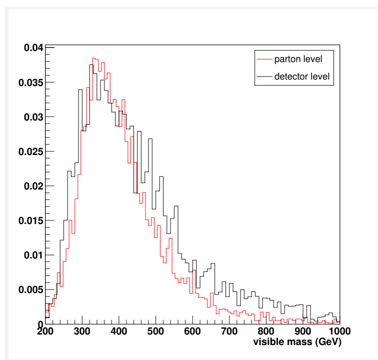
Vary $0 < \lambda < 2\lambda_{\rm SM}$: large σ_{hh} change @ low $m_{\rm vis}$ – love that interference!

Results for $hh \to 4W$ @ LHC



Notes:

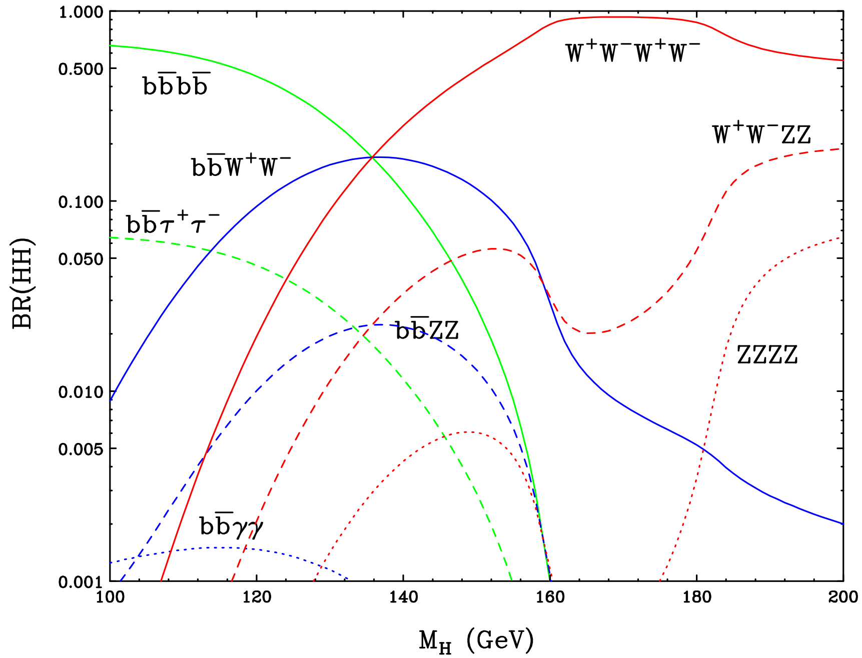
1. <u>LHC would exclude $\lambda_{3H} = 0$ at $\geq 95\%$ c.l. w/ 300 fb^{-1} for $150 < M_H < 200$ GeV</u>
2. double lumi (ATLAS+CMS) improves bounds $10 - 25\%$
3. SLHC (3000 fb^{-1}) can get λ_{3H} at $20 - 30\%$
4. ATLAS finds larger $t\bar{t}j$ background,
   but min. bias not a problem $\longrightarrow$



What about $M_H < 150$ GeV?

Possible channels:

- $b\bar{b}b\bar{b}$ – QCD 200x larger!
- $b\bar{b}\tau^+\tau^-$ – better, but too-low statistics
- $b\bar{b}W^+W^-$ – $t\bar{t}$ is bkg - forget it
- $b\bar{b}\gamma\gamma$ – rare mode works!



Backgrounds to $b\bar{b}\gamma\gamma$ to consider:

- $b\bar{b}\gamma\gamma$
- $c\bar{c}\gamma\gamma$ - 1 or 2 fake b jets
- $b\bar{b}j\gamma$ - 1 fake γ
- $c\bar{c}j\gamma$ - 1 or 2 fake b-jets, 1 fake γ
- $jj\gamma\gamma$ - 1 or 2 fake b-jets
- $b\bar{b}jj$ - 2 fake γ
- $c\bar{c}jj$ - 1 or 2 fake b-jets, 2 fake γ
- $jjj\gamma$ - 1 or 2 fake b-jets, 1 fake γ
- $jjjj$ - 1 or 2 fake b-jets, 2 fake γ
- Hjj - 1 or 2 fake b-jets, or 2 fake γ
- $Hj\gamma$ - 1 fake γ

	ϵ_γ	ϵ_μ	$P_{c\to b}$	$P_{j\to b}$	$P^{hi}_{j\to\gamma}$	$P^{lo}_{j\to\gamma}$
LHC	80%	90%	1/13	1/140	1/1600	1/2500
SLHC	80%	90%	1/13	1/23	1/1600	1/2500

▶ fakes are the worst background!

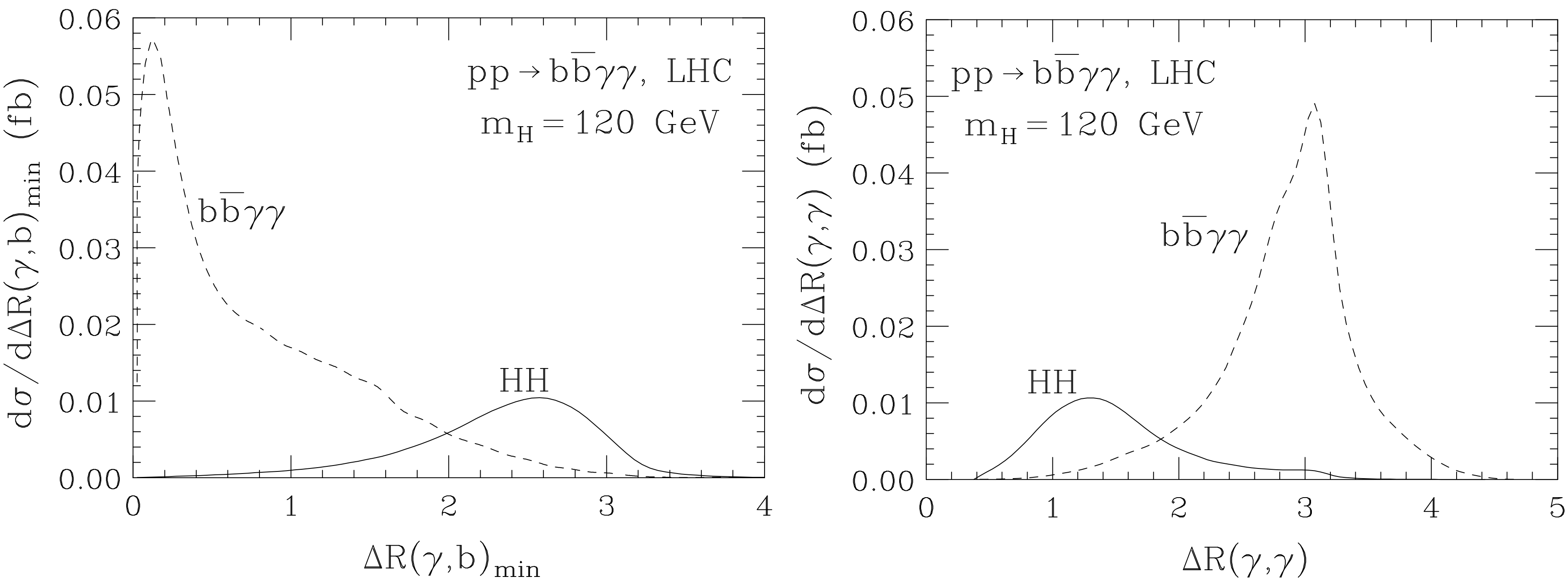
Note: huge QCD and detector uncertainties on these rates.

Is this a problem? $\longrightarrow$ not really

QCD uncertainties can be worked around if bkg shape is very different:

"pseudo sideband calibration"

$\longrightarrow$ QCD corrections *usually* do not alter angular distributions



► HH and $b\bar{b}\gamma\gamma$ shapes are very different, and in 2-D

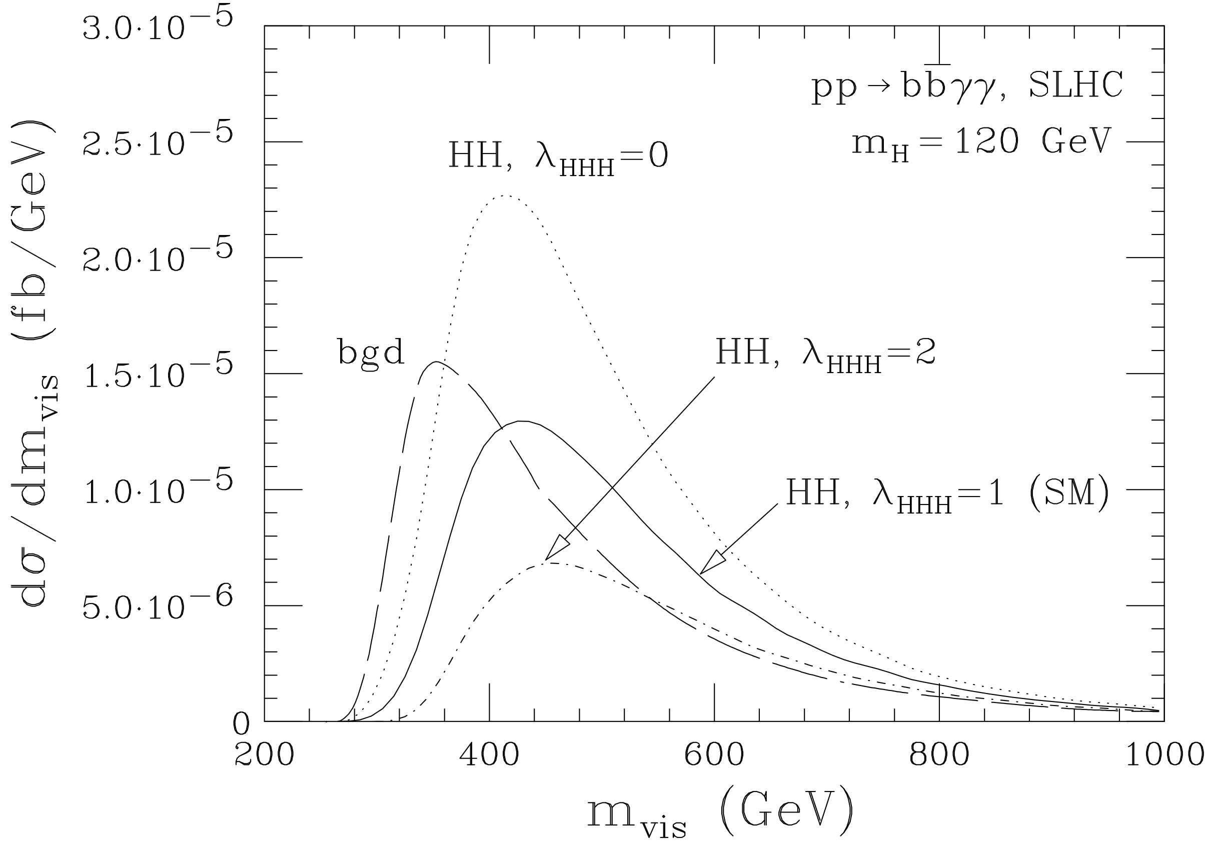
• bkg is measured in non-signal region and extrapolated;

drastically reduces systematic errors

Note: $m_{\rm vis}$ here is complete reconstruction

$HH \to b\bar{b}\gamma\gamma$ obviously needs a lot of statistics:

$\longrightarrow$ must consider SLHC (planned lumi upgrade to LHC: 3000 fb^{-1})



events expected for LHC, SLHC (600,6000 fb^{-1}): obviously marginal measurement

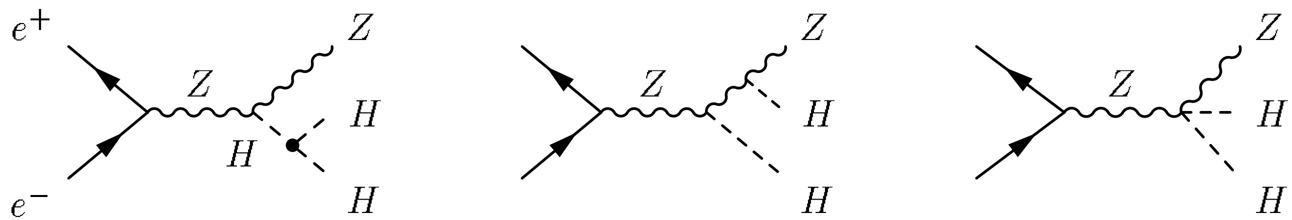
	hh	$b\bar{b}\gamma\gamma$	$c\bar{c}\gamma\gamma$	$b\bar{b}\gamma j$	$c\bar{c}\gamma j$	$jj\gamma\gamma$	$b\bar{b}jj$	$c\bar{c}jj$	γjjj	$jjjj$	$\sum(\mathrm{bkg})$	S/B
LHC	6	2	1	1	0	5	0	0	1	1	11	1/2
SLHC	21	6	0	4	0	6	1	0	1	1	20	1/1

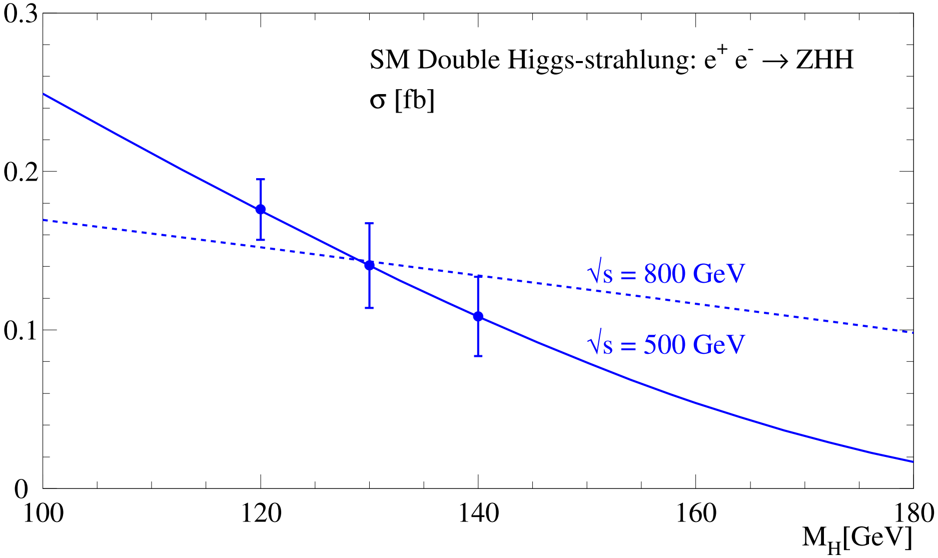
1 b-tag @ LHC, 2 b-tags @ SLHC (to overcome low fake rejection)

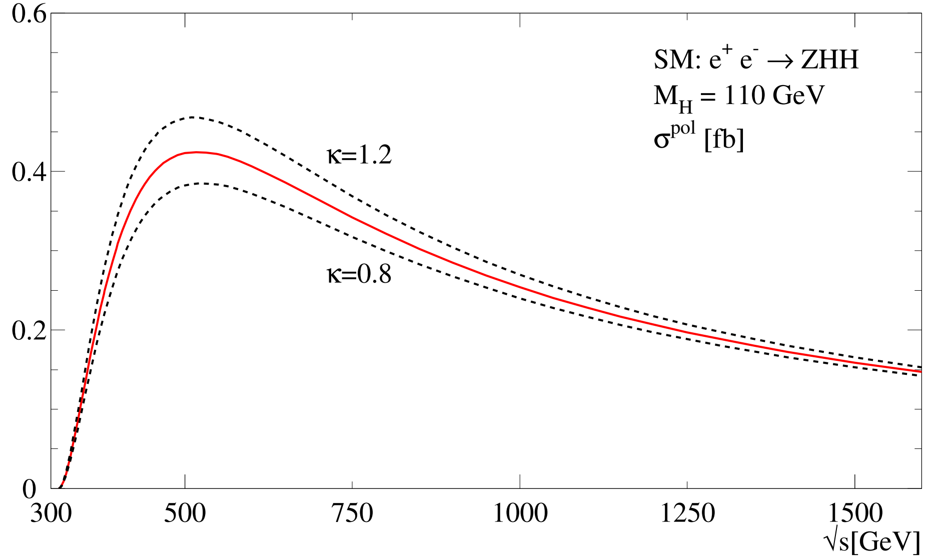
Step 2: HH at a linear collider

Double Higgs-strahlung:

$$e^+e^- \to ZHH$$

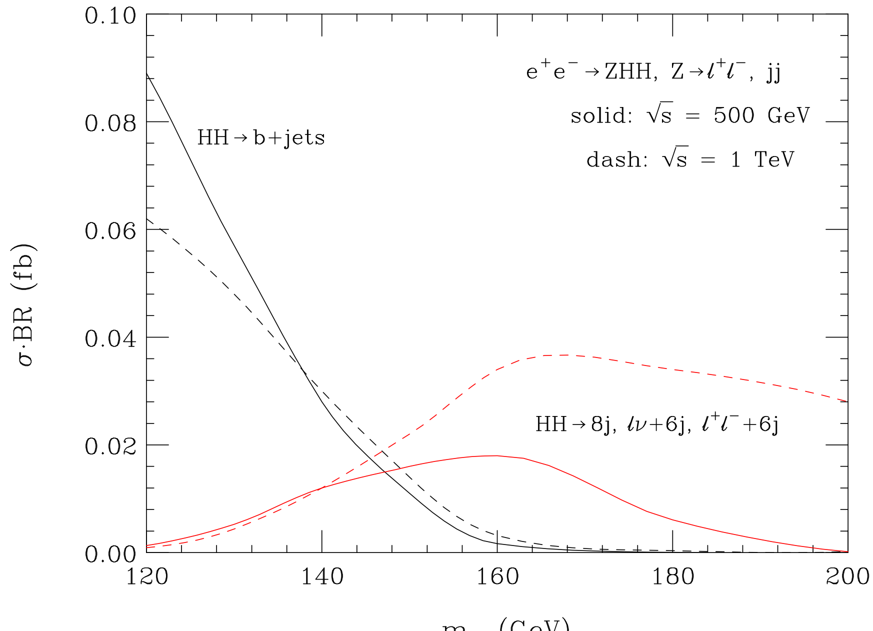






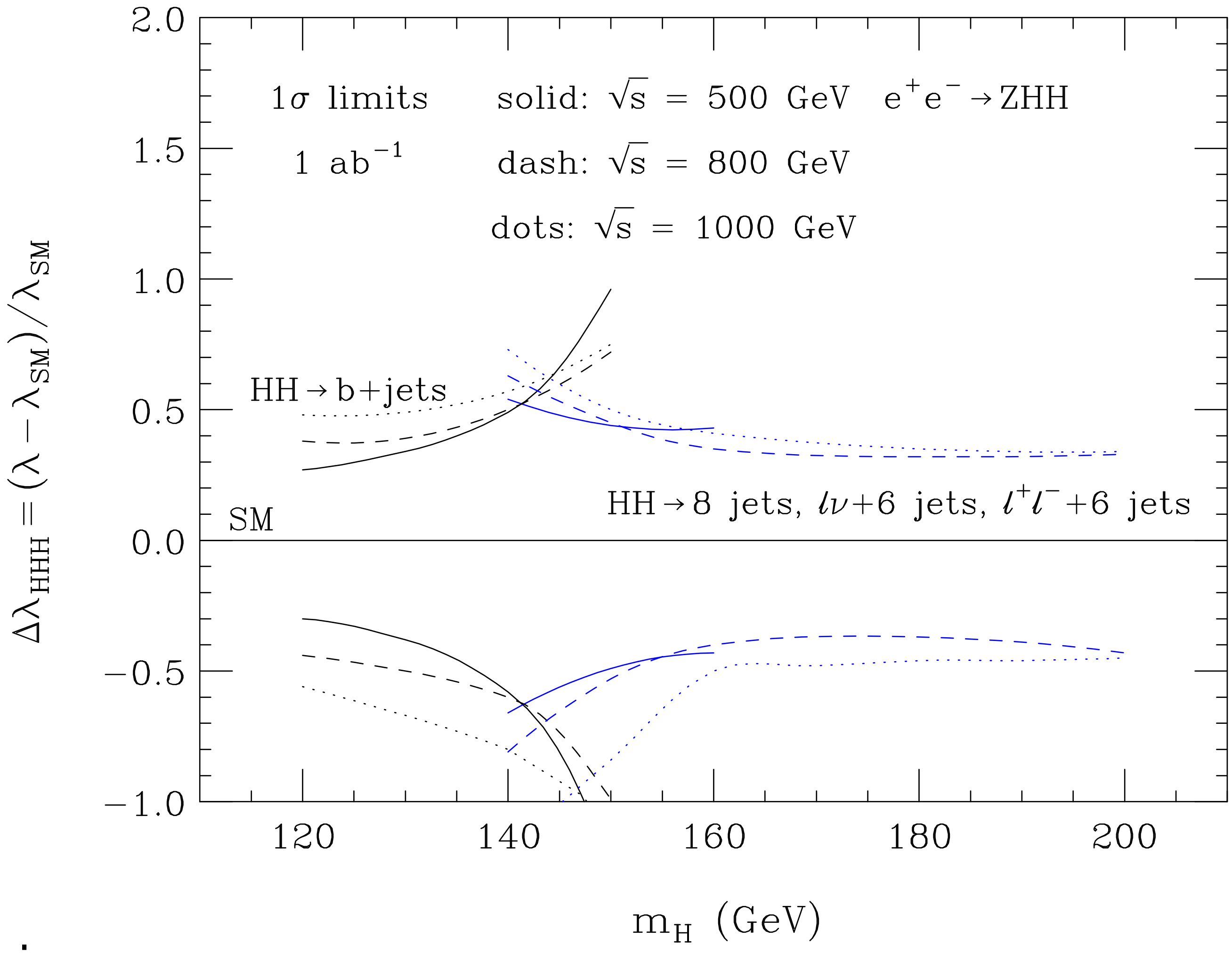
BR($4b$) falls steeply for low M_H

BR($4W$) is much flatter for hi M_H



Summary of what ILC could do

This is all parton level – desperately needs a detector simulation.

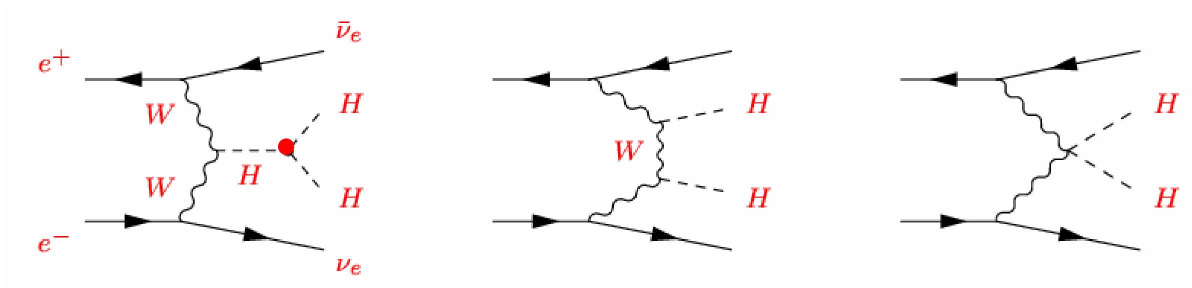


Conclusions:

LC is better for $M_H < 150$ GeV, SLHC is better for $M_H < 150$ GeV,
but SLHC would require precision LC input on Higgs couplings.

WW double-Higgs fusion:

$e^+e^- \to \bar{\nu}_e \nu_e HH$



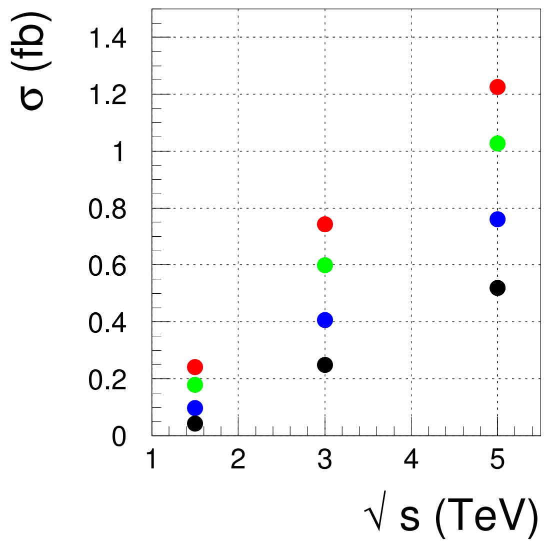
Small correction for $\sqrt{s} \lesssim 1$ TeV, important for $\sqrt{s} \gtrsim 1$ TeV.

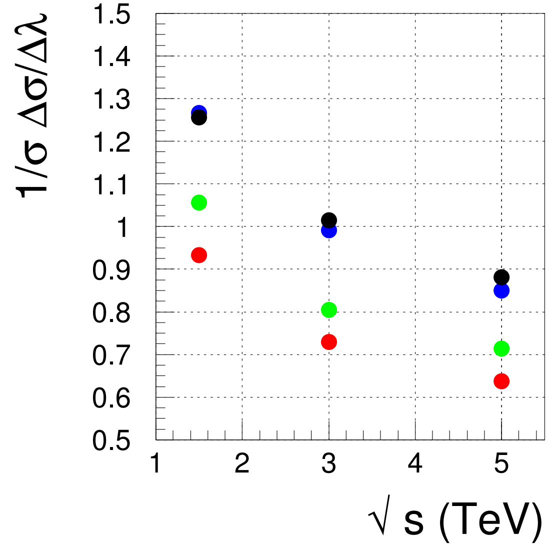
M_h = 120,140,180,240

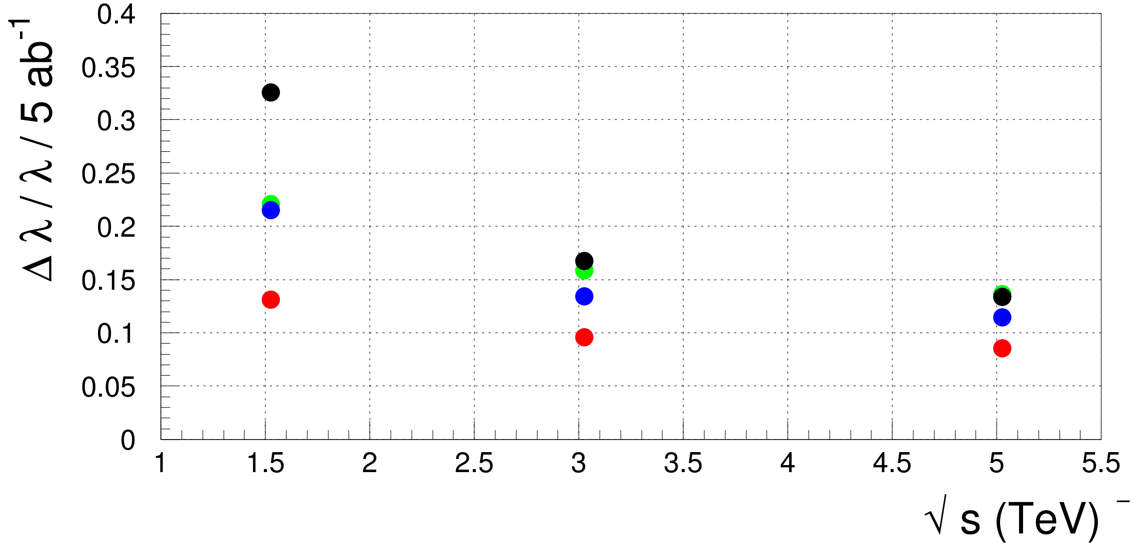
▶ really need CLIC

▶ limits limited by wash-out

of HHH diagram at large $\sqrt{s}$







EW corrections to λ in SM

$\longrightarrow$ leading 1-loop top quark effects:

$$\lambda_{HHH}^{eff} = \frac{M_H^2}{2v^2}\left[1 - \frac{N_C}{3\pi^2}\frac{m_t^4}{v^2 M_H^2} + \ldots\right]$$

(M_h, m_t are physical masses)

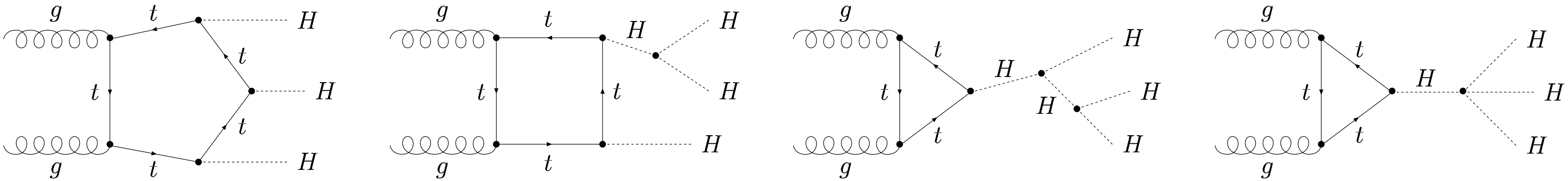
$\sim -10\%$ for $M_H = 120$ GeV

$\sim -\ \ 4\%$ for $M_H = 180$ GeV

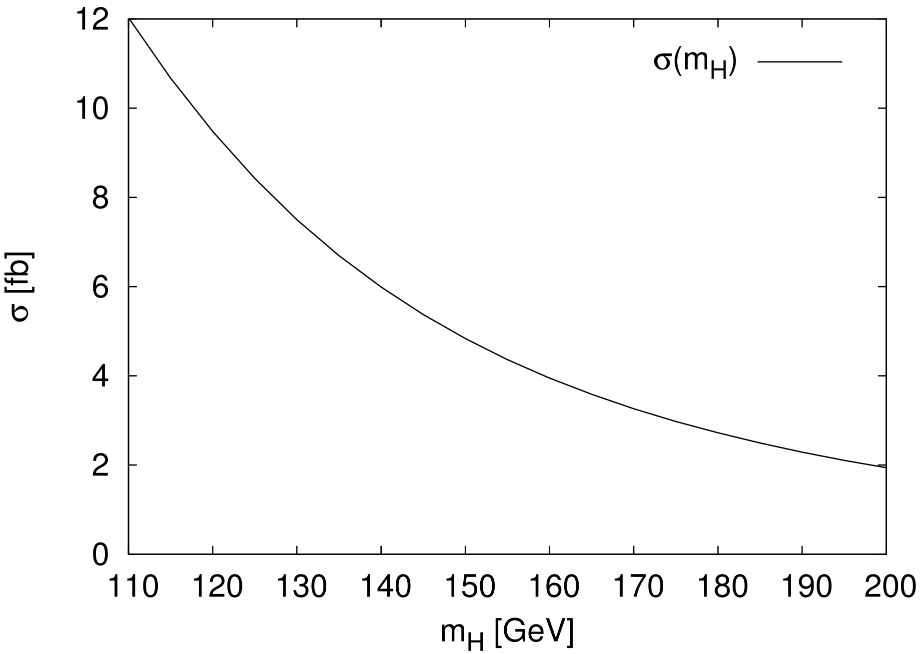
$\longrightarrow$ should take into account, but no sensitivity @ (S)LHC or ILC;
even CLIC is marginal, and only for low M_H

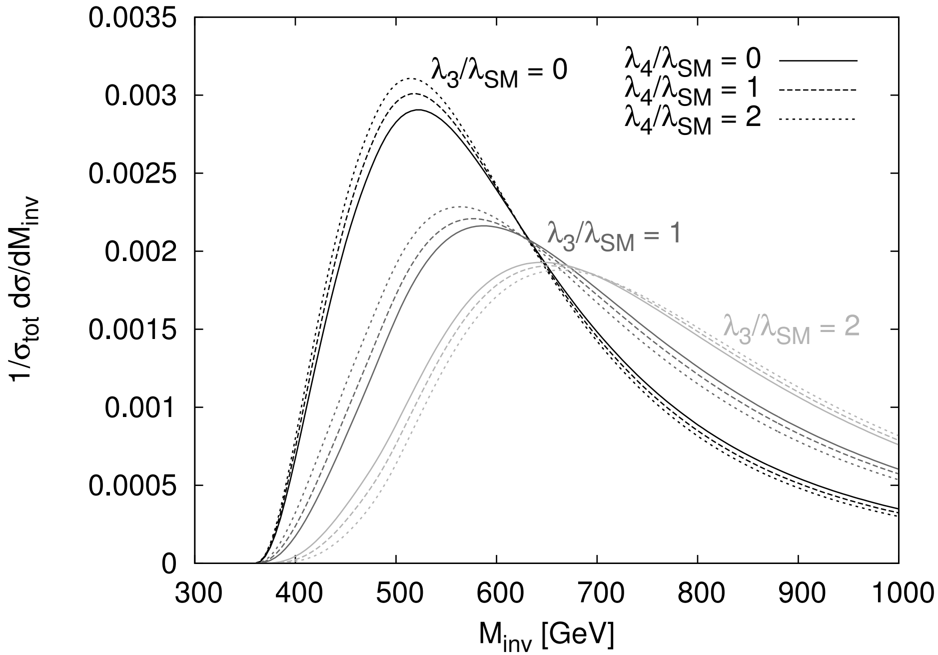
Step 3: HHH at LHC/VLHC (VLHC is $\sqrt{s} = 200$ TeV)

$gg \longrightarrow HHH$ will obviously be largest; this is:



Rates extremely low: (before BR's!)





$\longrightarrow \lambda_{4H}$ is washed out by other contributions

▷ this is not going to work

Step 4: HHH at ILC or CLIC or SFCLIC*

What are the rates? Note σ in *attobarn*:

$\sqrt{s}$	$\delta g_{4H} = -10\%$	g_{4H}^{SM}	$\delta g_{4H} = +10\%$
3 TeV	0.400 ab	0.390 ab	0.383 ab
5 TeV	1.385 ab	1.357 ab	1.321 ab
10 TeV	4.999 ab	4.972 ab	4.970 ab

factoid: 1 year of 10 TeV running at 1 ab^{-1}/yr yields 5 events

$\longrightarrow$ before BR's!

⊚ Broad conclusion:
measuring λ_{4H} is utterly hopeless, anywhere, ever

* Super-Fantasy-CLIC

Summary Part 2

- Observing a new Higgs-ish resonance is only the start!
- Charge & color quantum numbers are trivial;
  mass is a matter of precision, both experimental and theoretical.
- Spin & CP measurements are fairly straightfoward,
  although CP violation becomes tricky, really needs ILC.
- LHC can measure absolute Higgs gauge & Yukawa couplings
  with only $SU(2)_L$ as an underlying assumption.
- ILC can measure absolute Higgs gauge & Yukawa couplings
  without *any* underlying assumptions.
- Self-coups (Higgs potential) are *extremely* tough:
  · LHC is superior for $M_H \gtrsim 150$ GeV, but needs ILC precision input
  · ILC superior for $M_H \lesssim 150$ GeV
  · λ_{4H} is likely forever inaccessible